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That I am knowledgeable in the English language and in the language in which the below-identified Japanese application was filed, and that I believe the English translation of the Japanese Application No. 2002-308376, filed October 23, 2002, attached hereto is a true and complete translation of the above-identified Japanese application as filed.

I hereby declare that all statements made herein of my own knowledge are true, and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of this Verification, this application or any patent issued thereon.

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【Specification】

【Title of the invention】

MAGNETIC SENSOR, PRODUCTION PROCESS OF THE MAGNETIC SENSOR AND MAGNETIC ARRAY SUITABLE FOR THE PRODUCTION PROCESS

【Patent claims】

【Claim 1】

A magnetic sensor comprising a magnetoresistive effect element including a pinned layer and a free layer comprising:

a bias magnet film composed of a permanent magnet for producing a bias magnetic field in the free layer in a predetermined direction; and

an initializing coil that is provided in the vicinity of the free layer and applies to the free layer a magnetic field in the direction same as the direction of the bias magnetic field by being energized under a predetermined condition.

【Claim 2】

A production process of a magnetic sensor comprising, on a substrate, a pinned layer, a free layer and a bias magnet film being a permanent magnet that applies a bias magnetic field to the free layer to form a magnetoresistive effect element having a resistance value varying according to a relative angle made by a direction of magnetization in the pinned layer and a direction of magnetization in the free layer, comprising:

a step of preparing a magnet array configured such that plural permanent magnets are arranged on a lattice point of a tetragonal lattice

and a polarity of a magnet pole of each permanent magnet is different from a polarity of the other adjacent magnet pole spaced by the shortest route;

a step of manufacturing a wafer, including the substrates, on which plural island-like element films are interspersed, each element film including a film that becomes the pinned layer, a film that becomes the free layer and a film that becomes the bias magnet film; and

a step of disposing the wafer in the vicinity of the magnet array so as to establish a predetermined relative positional relationship between the wafer and the magnet array, whereby the film that becomes the bias magnet film of the plural element films is magnetized by utilizing a magnetic field formed between one magnet pole of the magnet poles of the magnet array and other magnet pole, of the magnet poles of the magnet array, that is adjacent to the one magnet pole spaced by the shortest route.

【Claim 3】

A production process of the magnetic sensor claimed in Claim 2, wherein

the step of manufacturing the wafer includes a step of forming each film, that becomes the free layer, of the plural element films in such a manner as to have a shape with a long axis and a short axis, and in such a manner that at least one of the long axes of the films that become the free layers of the plural element films is perpendicular to the long axis of the other film, that becomes the free layer, of the plural element films and a step of forming the film that becomes the bias magnet film at both ends of each film that becomes the free layer, in the direction of the long axis,

and wherein

the predetermined relative positional relationship in the step of magnetizing the film that becomes the bias magnet film is a relative positional relationship, between the wafer and the magnet array, that matches the direction of magnetization of the film that becomes the bias magnet film with the direction of the long axis of the film that becomes the free layer having the bias magnet film provided at both ends thereof, by a magnetic field formed by the magnet array.

【Claim 4】

A production process of the magnet sensor claimed in Claim 3, further comprising

a step of arranging the wafer in the vicinity of the magnet array so as to establish a relative positional relationship, between the wafer and the magnet array, that is different from the predetermined relative positional relationship, whereby the direction of magnetization of the film, that becomes the pinned layer, of the plural element films is pinned by utilizing the magnetic field formed by the magnet array.

【Claim 5】

A magnet array configured such that plural permanent magnets, each having an approximately rectangular parallelepiped shape in which the sectional shape perpendicular to one central axis of the rectangular parallelepiped is approximately square, are arranged such that the center of gravity of the edge face having approximately square shape is matched with a lattice point of the tetragonal lattice, and the polarity of the magnetic pole of each permanent magnet thus arranged is different from the polarity of the

magnetic pole of the adjacent other permanent magnet spaced by the shortest route.

[Detailed description of the invention]

[0001]

[Field of the Invention]

The present invention relates to a magnetic sensor using a magnetoresistive effect element including a pinned layer and a free layer, a production process of the magnetic sensor and a magnet array suitable for the production process.

[0002]

[Prior Arts]

Conventionally, a magnetoresistive effect element is applied to a magnetic sensor. For instance, the magnetoresistive effect element includes a giant magnetoresistive effect element (GMR element) or the like that is provided with a pinned layer having magnetization pinned (fixed) in a predetermined direction and a free layer in which the direction of magnetization is changed according to an external magnetic field and that presents a resistance value according to a relative relationship between the direction of magnetization in the pinned layer and the direction of magnetization in the free layer. In the magnetic sensor of this type, it is required that the direction of magnetization in each magnetic domain in the free layer in case where the external magnetic field is not applied to the magnetic sensor is stably maintained in a predetermined direction (this predetermined direction is referred to as "initial-state direction hereinafter) in order to accurately detect a minute external magnetic field.

【0003】

In general, a thin free layer is shaped into a rectangle as viewed in a plane and the long side (long axis) of the rectangular is matched to the initial-state direction, whereby the direction in each domain in the free layer is matched to the initial-state direction by utilizing a shape anisotropy in which the direction of magnetization is aligned in the longitudinal direction. Further, a bias magnet film that is a permanent magnet film is disposed at both end sections of the longitudinal direction of the free layer to apply the magnetization in the initial-state direction to the free layer so that the direction of magnetization in each magnetic domain in the free layer is returned to the initial-state direction, with a long-term stability, whenever the external magnetic field disappears.

【0004】

The state of magnetization in the free layer and the bias magnet film as described above will be explained with reference to Fig. 17 that is a plan view of the free layer and the bias magnet film. In Fig. 17, a free layer 100 is formed to have a longitudinal direction in an X-axis direction, and a pair of bias magnet films 101 and 102 are arranged at both ends of the longitudinal direction.

【0005】

At a stage of forming these films, the directions of magnetization in each magnetic domain of the free layer 100 and the bias magnet films 101 and 102 are not aligned to the initial-state direction that is the longitudinal direction of the free layer as shown by arrows in Fig. 17(A). When an external magnetic field whose magnitude is changed in a direction (Y-axis direction) perpendicular to the longitudinal direction of the free layer is

applied to the magnetic sensor in which the free layer 100 and the bias magnet films 101 and 102 are in above-mentioned state, for measuring a resistance value of the magnetic sensor, a hysteresis occurs as shown in Fig. 18(A). As apparent from this, in the magnetic sensor wherein the directions of magnetization in the free layer 100 and the bias magnet films 101 and 102 are not aligned to the longitudinal direction of the free layer, the resistance value for the external magnetic field being in the vicinity of "0" fluctuates in a range shown by an arrow in Fig. 18(A), resulting in that the magnetic sensor cannot accurately detect a minute magnetic field.

[0006]

Subsequently, when a magnetic field having a magnitude greater than a coersive force Hc of the bias magnet films 101 and 102 is applied in the longitudinal direction (X-axis positive direction) to the magnetic sensor in which the free layer 100 and the bias magnet films 101 and 102 are in a state shown in Fig. 17(A) in order to perform an initialization of the free layer 100 and the magnetization of the bias magnet films 101 and 102, the directions of magnetization in each magnetic domain in the free layer 100 and the bias magnet films 101 and 102 are matched to the initial-state direction as shown in Fig. 17(B).

[0007]

When an external magnetic field whose magnitude is changed within a range smaller than the coersive force Hc of the bias magnet films 101 and 102 in the Y-axis direction is applied to the magnetic sensor which is in the above-mentioned state, the direction of magnetization in the magnetic domain in the free layer 100 is changed as shown in Fig. 17(C), and then, after eliminating the external magnetic field, the direction of magnetization in

each magnetic domain in the free layer 100 is returned to the initial-state direction as shown in Fig. 17(D) like that as shown in Fig. 17(B). When the resistance value of the magnetic sensor is measured in this case, the hysteresis is decreased, so that the resistance value for the external magnetic field being in the vicinity of "0" becomes approximately constant. Accordingly, the magnetic sensor having the free layer 100 initialized and the bias magnet films 101 and 102 magnetized can accurately detect a minute magnetic field.

【0008】

【Problems to be solved by the invention】

However, when an external magnetic field having a magnitude smaller than the coersive force of the magnet films 101 and 102 but relatively great and having a main component in the direction (X-axis negative direction) reverse to the initial-state direction is applied to the magnetic sensor (the magnetic sensor having the free layer 100 initialized and the bias magnet films 101 and 102 magnetized), the direction of magnetization in each magnetic domain in the free layer is changed from the state shown in Fig. 19(A) to the state shown in Fig. 19(B), and even if the external magnetic field is eliminated, the direction of magnetization in each magnetic domain in the free layer 100 does not match (return) to the initial-state direction. As a result, the magnetic sensor has a hysteresis again with respect to the external magnetic field, entailing a problem of deteriorating the detection accuracy of the magnetic field.

【0009】

Accordingly, one of objects of the present invention is to provide a magnetic sensor capable of satisfactorily maintaining a detection accuracy

even after a great external magnetic field is applied thereto. Further, another object of the present invention is to provide a magnetic sensor capable of efficiently magnetizing the aforesaid bias magnet films, a production process of the magnetic sensor and a magnet array suitable for the production process.

[0010]

[Summary of the invention]

According to the feature of the present invention, a magnetic sensor comprising a magnetoresistive effect element including a pinned layer and a free layer comprises a bias magnet film composed of a permanent magnet for producing a bias magnet field for (in) the free layer in a predetermined direction and an initializing coil that is provided in the vicinity of the free layer and applies to the free layer a magnetic field in the direction same as the direction of the bias magnetic field by being energized under a predetermined condition.

[0011]

According to the above structure, the initializing coil is energized under a predetermined condition to thereby generate an initializing magnetic field for returning the direction of magnetization in each magnetic domain in the free layer to the direction same as the direction of the bias magnetic field by the bias magnet film, whereby the direction of magnetization in each magnetic domain in the free layer can be corrected even if the direction of magnetization is disturbed due to some reason such as when a strong magnetic field is applied to the magnetic sensor. As a result, a change in the resistance value to the magnetic field does not have hysteresis, whereby a magnetic sensor can be provided that can detect even a minute magnetic

field with high precision over a long period.

[0012]

Another feature of the present invention is that a production process of a magnetic sensor comprising, on a substrate, a pinned layer, a free layer and a bias magnet film being a permanent magnet that applies a bias magnetic field to the free layer to form a magnetoresistive effect element having a resistance value varying according to a relative angle made by a direction of magnetization in the pinned layer and a direction of magnetization in the free layer, comprises a step of preparing a magnet array configured such that plural permanent magnets are arranged on a lattice point of a tetragonal lattice and a polarity of a magnet pole of each permanent magnet is different from a polarity of the other adjacent magnet pole spaced by the shortest route (i.e., shortest distance), a step of manufacturing a wafer, including the substrate(s), on which plural island-like element films are interspersed, each element film including a film that becomes the pinned layer, a film that becomes the free layer and a film that becomes the bias magnet film and a step of disposing (placing, arranging) the wafer in the vicinity of the magnet array so as to establish a predetermined relative positional relationship between the wafer and the magnet array and magnetizing the film that becomes the bias magnet film of the plural element films by utilizing a magnetic field formed between one magnet pole of the magnet poles of the magnet array and other magnet pole, of the magnet poles of the magnet array, that is adjacent to the one magnet pole spaced by the shortest route (from the one magnet pole).

[0013]

The magnet array is configured such that plural permanent magnets

are arranged at a lattice point of a tetragonal lattice and the polarity of the magnetic pole of each permanent magnet is different from the polarity of the other adjacent magnetic pole spaced by the shortest route (in the same plane), as viewed in a plane. Accordingly, the following magnetic fields are formed above the magnet array as viewed in a plane of the magnet array: a magnetic filed formed from one N-pole in the rightward direction to S-pole that is present at the right side of the N-pole, a magnetic field formed from the N-pole in the upward direction to S-pole that is present at the upper side of the N-pole, a magnetic field formed from the N-pole in the leftward direction to S-pole that is present at the left side of the N-pole and a magnetic field formed from the N-pole in the downward direction to S-pole that is present at the lower side of the N-pole (see Fig. 13). Similarly, the following magnetic fields are formed to (toward) some S-pole: a magnetic field formed in the leftward direction from N-pole that is present at the right side of this S-pole, a magnetic field formed in the downward direction from N-pole that is present at the upper side of this S-pole, a magnetic field formed in the rightward direction from N-pole that is present at the left side of this S-pole and a magnetic field formed in the upward direction from N-pole that is present at the lower side of this S-pole.

[0014]

In this process, a wafer, including the substrate(s), on which plural island-like element films is interspersed, each element film including a film that becomes the pinned layer, a film that becomes the free layer and a film that becomes the bias magnet film is disposed (placed, set, or arranged) in the vicinity of the magnet array so as to establish a predetermined relative positional relationship between the wafer and the magnet array and thereby

the film that becomes the bias magnet film of the plural element films is magnetized by utilizing the above-mentioned magnetic field formed by the magnet array. Therefore, a magnetic sensor wherein magnetization directions of the bias magnet films are crossed (perpendicular in this case) to each other on a single substrate (a monolithic substrate) can efficiently be manufactured.

[0015]

More specifically, the step of manufacturing the wafer includes a step of forming each film, that becomes the free layer, of the plural element films in such a manner as to have a shape with a long axis and a short axis, and in such a manner that at least one of the long axes of the films, that become the free layes, of the plural element films is perpendicular to the long axis of the other film, that becomes the free layer, of the plural element films, and a step of forming the film that becomes the bias magnet film at both ends of each film, that becomes the free layer, in the direction of the long axis, wherein the predetermined relative positional relationship in the step of magnetizing the film that becomes the bias magnet film is a relative relationship, between the wafer and the magnet array, that matches the direction of magnetization of the film that becomes the bias magnet film with the direction of the long axis of the film that becomes the free layer having the bias magnet film provided at both ends thereof, by a magnetic field formed by the magnet array.

[0016]

Further, in this case, it is preferable to include a step of arranging the wafer in the vicinity of the magnet array so as to establish a relative positional relationship, between the wafer and the magnet array, that is

different from the predetermined relative positional relationship, whereby the direction of magnetization of the film, that becomes the pinned layer, of the plural element films is pinned by utilizing the magnetic field formed by the magnet array.

[0017]

According to this method, the magnet array used for magnetizing the film that becomes the bias magnet film is also used for fixing the direction of magnetization in the pinned layer, whereby a magnetic sensor (two-axis magnetic sensor that can detect the respective magnetic fields whose directions are perpendicular to each other) wherein magnetization directions of the bias magnet films are crossed (perpendicular in this case) to each other on a single substrate can efficiently be manufactured with low cost.

[0018]

Moreover, the present invention provides a magnet array configured such that plural permanent magnets, each having an approximately rectangular parallelepiped shape in which the sectional shape perpendicular to one central axis of the rectangular parallelepiped is approximately square, are arranged such that the center of gravity of the edge face having approximately square shape is matched with a lattice point of the tetragonal lattice, and the polarity of the magnetic pole (the polarity of the magnetic pole that appear at the edge face) of each permanent magnet thus arranged is different from the polarity of the magnetic pole of the adjacent other permanent magnet spaced by the shortest route.

[0019]

As described above, magnetizing each film that becomes the bias magnet film and/or fixing the direction of magnetization in the layer that

becomes the pinned layer of the above-mentioned two-axis magnetic sensor can efficiently be performed by using the magnet array, for example. Therefore, with the magnet array, it is possible to manufacture the two-axis magnetic sensor with low cost.

[0020]

[Embodiments of the invention]

Embodiments of a magnetic sensor in accordance with the present invention will now be described with reference to the drawings. This magnetic sensor is classified into N-type and S-type depending upon a production process described later. Fig. 1 is a plan view wherein an N-type magnetic sensor 10 and an S-type magnetic sensor 50 are placed side by side. The N-type magnetic sensor 10 and the S-type magnetic sensor 50 have substantially the same shape and same configuration except that a direction of fixed magnetization in a pinned layer shown by black-solid arrows in Fig. 1 and a direction of magnetization in an initial state in a free layer shown by outline arrows in Fig. 1 are different from each other. Accordingly, the following explanation is mainly focused on the N-type magnetic sensor 10.

[0021]

The magnetic sensor 10 comprises, as shown in Fig. 1, a single chip (a single substrate or a monolithic chip) 10a made of a quartz glass, which has a rectangular shape (almost square shape) viewed in a plane having sides along an X-axis direction and Y-axis direction perpendicular to each other, and has a little thickness in a Z-axis direction perpendicular to the X-axis and Y-axis, plural insulating layers 10b (wiring layers are included in this insulating layers) laminated on the substrate 10a shown in Fig. 3, a total

of eight GMR elements 11 to 14, 21 to 24 formed on the uppermost layer 10b1 of the insulating layers 10b and a total of eight initializing coils (coils for initializing) 31 to 34 and 41 to 44.

[0022]

The first X-axis GMR element 11 is formed at a portion a little downward from the almost central part in the Y-axis direction of the chip 10a and in the vicinity of an end portion of the X-axis negative direction. The direction of pinned magnetization of the pinned layer of the GMR element 11 is in the X-axis negative direction as shown by a black-solid arrow in Fig. 1. The second X-axis GMR element 12 is formed at a portion a little upward from the almost central part in the Y-axis direction of the chip 10a and in the vicinity of the end portion of the X-axis negative direction. The direction of pinned magnetization of the pinned layer of the GMR element 12 is in the X-axis negative direction shown by a black-solid arrow in Fig. 1. The third X-axis GMR element 13 is formed at a portion a little upward from the almost central part in the Y-axis direction of the chip 10a and in the vicinity of an end portion of the X-axis positive direction. The direction of pinned magnetization of the pinned layer of the GMR element 13 is in the X-axis positive direction as shown by a black-solid arrow in Fig. 1. The fourth X-axis GMR element 14 is formed at a portion a little downward from the almost central part in the Y-axis direction of the chip 10a and in the vicinity of the end portion of the X-axis positive direction. The direction of pinned magnetization of the pinned layer of the GMR element 14 is in the X-axis positive direction shown by a black-solid arrow in Fig. 1.

[0023]

The first Y-axis GMR element 21 is formed at a portion a little

leftward from the almost central part in the X-axis direction of the chip 10a and in the vicinity of an end portion of the Y-axis positive direction. The direction of pinned magnetization of the pinned layer of the GMR element 21 is in the Y-axis positive direction as shown by a black-solid arrow in Fig. 1. The second Y-axis GMR element 22 is formed at a portion a little rightward from the almost central part in the X-axis direction of the chip 10a and in the vicinity of the end portion of the Y-axis positive direction. The direction of pinned magnetization of the pinned layer of the GMR element 22 is in the Y-axis positive direction shown by a black-solid arrow in Fig. 1. The third Y-axis GMR element 23 is formed at a portion a little rightward from the almost central part in the X-axis direction of the chip 10a and in the vicinity of an end portion of the Y-axis negative direction. The direction of pinned magnetization of the pinned layer of the GMR element 23 is in the Y-axis negative direction as shown by a black-solid arrow in Fig. 1. The fourth Y-axis GMR element 24 is formed at a portion a little leftward from the almost central part in the X-axis direction of the chip 10a and in the vicinity of the end portion of the Y-axis negative direction. The direction of pinned magnetization of the pinned layer of the GMR element 24 is in the Y-axis negative direction shown by a black-solid arrow in Fig. 1.

【0024】

Each of the GMR elements 11 to 14 and 21 to 24 has substantially the same structure except for the position on the chip 10a. Therefore, the first X-axis GMR element 11 is taken as a representative example hereinbelow for explaining the structure thereof.

【0025】

The first X-axis GMR element 11 comprises, as shown in Fig. 2 that

is a plan view and Fig. 3 that is a schematic sectional view of the first X-axis GMR element 11 cut by a plane along a line of 1 - 1 in Fig. 2, a plurality of narrow zonal portions 11a ..... 11a made of a spin valve film SV and having a longitudinal direction in the Y-axis direction and bias magnet films (hard ferromagnetic thin film layer and become a permanent magnet film by magnetization) 11b ..... 11b that are made of hard ferromagnetic materials, having high coercive force and high squareness ratio, such as CoCrPt. Each of the narrow zonal portions 11a ..... 11a extends in the X-axis direction on the upper surface of each of the bias magnet films 11b ..... 11b, and joins to the adjacent narrow zonal portion 11a to thereby form a so-called "zig-zag shape" as well as to thereby magnetically join to each of the bias magnet films 11b ..... 11b at the upper surface of each of the bias magnet films 11b ..... 11b.

[0026]

As shown in Fig. 4 that illustrates the film structure, the spin valve film SV of the first X-axis GMR element 11 includes a free layer F, a conductive spacer layer S made of Cu having a thickness of 2.4 nm (24A), a fixed layer (pin layer) P and a capping layer C made of titanium (Ti) or tantalum (Ta) having a thickness of 2.5 nm (25A), which are laminated in this order on the chip 10a serving as a substrate.

[0027]

The free layer F is a layer whose magnetization direction varies in accordance with the direction of the external magnetic field, and comprises a CoZrNb amorphous magnetic layer 11-1 formed directly on the substrate 10a and having a film thickness of 8 nm (80A), a NiFe magnetic layer 11-2 formed on the CoZrNb amorphous magnetic layer 11-1 and having a film

thickness of 3.3 nm (33A), and a CoFe layer 11-3 formed on the NiFe magnetic layer 11-2 and having a film thickness of approximately 1 to 3 nm (10 to 30A). The CoZrNb amorphous magnetic layer 11-1 and NiFe magnetic layer 11-2 constitute a soft ferromagnetic material thin film layer. The CoFe layer 11-3 prevents Ni of the NiFe magnetic layer 11-2 and Cu 11-4 of the spacer layer S from diffusing.

【0028】

The fixed layer (pin layer) P is made by superposing a CoFe magnetic layer 11-5 having a film thickness of 2.2 nm (22A), and an antiferromagnetic film 11-6 which is formed of a PtMn alloy including 45 to 55 mol% of Pt and has a film thickness of 24 nm (240A). The CoFe magnetic layer 11-5 is in an exchange coupling manner to the magnetized antiferromagnetic film 11-6. Thus, the direction of magnetization (magnetizing vector) of the CoFe magnetic layer 11-5 is pinned (fixed) in the X-axis negative direction as described above.

【0029】

The bias magnet films 11b ..... 11b gives a bias magnetic field to the free layer F in the Y-axis negative direction (the direction shown by the outline arrow in Figs. 1 and 2) that is the longitudinal direction of the free layer F in order to maintain uniaxial anisotropy of the free layer F.

【0030】

The first X-axis GMR element 11 thus configured presents a resistance value, which changes in almost proportion to the external magnetic field that changes along the X-axis within a range of -Hc to +Hc, as indicated by the solid line of Fig. 5, and presents an almost constant resistance value to the external magnetic field that changes along the Y-axis,

as indicated by the broken line of Fig. 5.

[0031]

Subsequently, the initializing coils 31 to 34 and 41 to 44 are explained. The initializing coils 31 to 34 and 41 to 44 are buried in the lower insulating layer 10b2 under the uppermost layer 10b1 of the insulating layers. The initializing coils 31 to 34 and 41 to 44 are positioned approximately immediately below each of the GMR elements 11 to 14 and 21 to 24, respectively. Each of the initializing coils 31 to 34 and 41 to 44 has the same shape to one another, and its relative positional relationship to the corresponding GMR element immediately above each coil is the same to one another. Each of the initializing coils 31 to 34 and 41 to 44 applies the initializing magnetic field in the direction shown by the outline arrow in Fig. 1 to each corresponding GMR element.

[0032]

The following explanation is made by taking the initializing coil 31 as a representative example. This initializing coil 31 is wound so as to have an approximately rectangular outer shape viewed in a plane, and comprises plural initializing magnetic field generating sections 31a ..... 31a extending linearly in the direction (X-axis direction) perpendicular to the longitudinal direction of the narrow zonal portions 11a of the first X-axis GMR element 11 at a region immediately below the first X-axis GMR element 11 viewed in a plane. Further, one end 31b and the other end 31c of the initializing coil 31 are connected to a positive polarity and negative polarity of a constant voltage source respectively. When a predetermined condition is established, predetermined current is made to flow through the initializing coil 31, thereby applying the initializing magnetic field in the Y-axis negative

direction to the narrow zonal portion 11a of the first X-axis GMR element 11 as shown by the outline arrow in Fig. 1.

[0033]

Subsequently explained are an X-axis magnetic sensor (a magnetic sensor with a magnetic field detecting direction which is the X-axis direction) and a Y-axis magnetic sensor (a magnetic sensor with a magnetic field detecting direction which is the Y-axis direction) composed respectively of the GMR elements 11 to 14 and 21 to 24. As shown by an equivalent circuit in Fig. 6(A), the X-axis magnetic sensor is formed such that the first to fourth X-axis GMR elements 11 to 14 are full-bridge-connected via a conductor not shown in Fig. 1. In Fig. 6(A), each graph shown at the position adjacent to each of the first to fourth GMR elements 11 to 14 indicates a characteristic (change in the resistance value R with respect to the external magnetic field) of the GMR element adjacent to each graph. This is also true in Figs. 7 to 9. Symbols Hx and Hy in these graphs respectively indicate the external magnetic field whose magnitude varies along the X-axis and Y-axis.

[0034]

In this configuration, a connection point between the first X-axis GMR element 11 and the fourth X-axis GMR element 14 and a connection point between the second X-axis GMR element 12 and the third X-axis GMR element 13 are respectively connected to the positive polarity and the negative polarity (ground) of the constant voltage source, whereby a potential of +V (5 (V) in this embodiment) and a potential -V (0 (V) in this embodiment) are respectively applied thereto. Then, a difference in potential V_{0X} between a connection point of the first X-axis GMR element 11

and the third X-axis GMR element 13 and a connection point of the fourth X-axis GMR element 14 and the second X-axis GMR element 12 are taken out as a sensor output. As a result, the X-axis magnetic sensor outputs, as shown in Fig. 6(B), an output voltage V_{ox} that varies in approximately proportion to the external magnetic field Hx that changes along the X-axis.

[0035]

As shown by an equivalent circuit in Fig. 7(A), the Y-axis magnetic sensor is formed such that the first to fourth Y-axis GMR elements 21 to 24 are full-bridge-connected via a conductor not shown in Fig. 1. A connection point between the first Y-axis GMR element 21 and the fourth Y-axis GMR element 24 and a connection point between the second Y-axis GMR element 22 and the third Y-axis GMR element 23 are respectively connected to the positive polarity and the negative polarity (ground) of the constant voltage source, whereby a potential of +V (5 (V) in this embodiment) and a potential of -V (0 (V) in this embodiment) are respectively applied thereto. Then, a difference in potential V_{0y} between a connection point of the first Y-axis GMR element 21 and the third Y-axis GMR element 23 and a connection point of the fourth Y-axis GMR element 24 and the second Y-axis GMR element 22 are taken out as a sensor output. As a result, the Y-axis magnetic sensor outputs, as shown in Fig. 7(B), an output voltage V_{oy} that varies in approximately proportion to the external magnetic field Hy that changes along the Y-axis. The above description is about the configuration of the N-type magnetic sensor 10.

[0036]

On the other hand, the S-type magnetic sensor 50 includes GMR elements 51 to 54 and 61 to 64 and initializing coils 71 to 74 and 81 to 84 as

shown in Fig. 1. The S-type magnetic sensor 50 has the substantially same structure as that of the magnetic sensor 10 and includes the X-axis magnetic sensor and Y-axis magnetic sensor.

[0037]

Specifically, as shown by an equivalent circuit in Fig. 8(A), the X-axis magnetic sensor is formed such that the first to fourth X-axis GMR elements 51 to 54 are full-bridge-connected via a conductor not shown in Fig. 1. In this configuration, a connection point between the first X-axis GMR element 51 and the fourth X-axis GMR element 54 and a connection point between the second X-axis GMR element 52 and the third X-axis GMR element 53 are respectively connected to the positive polarity and the negative polarity (ground) of the constant voltage source, whereby a potential of +V (5 (V) in this embodiment) and a potential of -V (0 (V) in this embodiment) are respectively applied thereto. Then, a difference in potential V_{0X} between a connection point of the first X-axis GMR element 51 and the third X-axis GMR element 53 and a connection point of the fourth X-axis GMR element 54 and the second X-axis GMR element 52 are taken out as a sensor output. As a result, the X-axis magnetic sensor outputs, as shown in Fig. 8(B), an output voltage V_{ox} that varies in approximately proportion to the external magnetic field Hx that changes along the X-axis.

[0038]

Further, as shown by an equivalent circuit in Fig. 9(A), the Y-axis magnetic sensor of the magnetic sensor 50 is formed such that the first to fourth Y-axis GMR elements 61 to 64 are full-bridge-connected via a conductor not shown in Fig. 1. A connection point between the first Y-axis GMR element 61 and the fourth Y-axis GMR element 64 and a connection

point between the second Y-axis GMR element 62 and the third Y-axis GMR element 63 are respectively connected to the positive polarity and the negative polarity (ground) of the constant voltage source, whereby a potential of +V (5 (V) in this embodiment) and a potential -V (0 (V) in this embodiment) are respectively applied thereto. Then, a difference in potential V_{0y} between a connection point of the first Y-axis GMR element 61 and the third Y-axis GMR element 63 and a connection point of the fourth Y-axis GMR element 64 and the second Y-axis GMR element 62 are taken out as a sensor output. As a result, the Y-axis magnetic sensor outputs, as shown in Fig. 9(B), an output voltage V_{0y} that varies in approximately proportion to the external magnetic field Hy that changes along the Y-axis.

[0039]

Subsequently explained is a process for manufacturing the magnetic sensors 10 and 50 thus configured as described above. Firstly, each insulating layer 10b is laminated on a rectangular quartz glass 10a1, that becomes the substrates 10a and 50a later, with the formation of a predetermined wiring or LSI, followed by forming the initializing coils 31 to 34, 41 to 44, 71 to 74 and 81 to 84 in the insulating layer 10b2, and then, the uppermost insulating layer 10b1 is formed (see Figs. 1 to 3).

[0040]

Then, plural films M composing the GMR elements 11 to 14, 21 to 24, 51 to 54 and 61 to 64 are formed like an island. This film formation is performed by using a ultra-high vacuum device in a manner of continuous laminating with a precise thickness. These films M are formed to be arranged at each position of the GMR elements 11 to 14, 21 to 24, 51 to 54 and 61 to 64 shown in Fig. 1 when the quarts glass 10a1 is cut along the

broken line in Fig. 10 by a subsequent cutting process to thereby be divided into the individual magnetic sensor 10 and 50 shown in Fig. 1.

[0041]

Subsequently, as shown in Fig. 11 that is a plan view, a rectangular metal plate 91 is prepared that is provided only with plural square through-holes arranged in a tetragonal lattice (i.e., square through-holes each having sides parallel to the X-axis and Y-axis are arranged along the X-axis and Y-axis so as to be spaced at equal intervals). Each of permanent bar magnets 92 ..... 92 with a shape of a rectangular parallelepiped having a square section approximately equal to each through-hole is inserted into each through-hole such that the edge face having a magnetic pole of the permanent bar magnet 92 ..... 92 formed thereon becomes parallel to the metal plate 91. At this time, the permanent bar magnets 92 ..... 92 are arranged such that the polarity of the magnetic pole is different from the adjacent polarity by the shortest route in a plane including each edge face of the permanent bar magnets 92 ..... 92. It is to be noted that each of the used permanent bar magnets 92 ..... 92 has magnetic charge whose magnitude is approximately equal to one another.

[0042]

Then, as shown in Fig. 12 that represents a section along X-Z plane, a plate 92 is prepared that is made of a transparent quartz glass having a thickness of about 0.5 mm and having a rectangular shape approximately equal to the metal plate 91. Thereafter, the upper surface (the surface opposite to the edge face on which the magnetic pole is formed) of the permanent bar magnets 92 ..... 92 and the bottom surface of the plate 93 are bonded by an adhesive, and then, the metal plate 91 is removed from

below. At this stage, a magnet array MA is formed by the permanent bar magnets 92 ..... 92 and the plate 93, wherein plural permanent magnets, each having an approximately rectangular parallelepiped shape in which the sectional shape perpendicular to one central axis of the rectangular parallelepiped is approximately square, are arranged such that the center of gravity of the edge face having approximately square shape is matched with a lattice point of the tetragonal lattice, and the polarity of the magnetic pole of each permanent magnet thus arranged is different from the polarity of the magnetic pole of the adjacent other permanent magnet spaced by the shortest route.

[0043]

Fig. 13 is a perspective view showing a state wherein only four permanent bar magnets 92 ..... 92 are taken out. As apparent from this figure, there are magnetic fields formed on the edge face (the edge face on which the magnetic pole is formed) of the permanent bar magnet 92 .... 92, the magnetic fields from one N-pole directing to the S-poles adjacent to this N-pole by the shortest route and each having a different direction at an angle of 90 degrees. In this embodiment, this magnetic field is used as a magnetic field for magnetizing each bias magnet film 11b to 14b, 21b to 24b, 51b to 54b and 61b to 64b of each GMR element 11 to 14, 21 to 24, 51 to 54 and 61 to 64 and as a magnetic field for fixing the direction of magnetization in each fixed layer P (pinned layer in the fixed layer P).

[0044]

Specifically, as shown in Fig. 14, the quartz glass 10a1 on which the film M which will become the GMR element is formed is firstly arranged such that the face having the film M which will become the GMR element formed

thereon comes in contact with the upper surface of the plate 93, and then, the plate 93 and the quartz glass 10a1 are fixed to each other by a cramp C. At this time, as shown in Fig. 15 that is a plan view for enlarging the section that becomes later the magnetic sensors 10 and 50 by paying attention to the section corresponding to two of the magnetic sensors 10 and 50, the quartz glass 10a1 and the magnet array MA are relatively arranged such that each cross-point CP of the cutting plane line CL of the quartz glass 10a1 that becomes each side of the magnetic sensors 10 and 50 is matched with the respective center of gravity of the permanent bar magnets 92 ..... 92. Accordingly, as shown by arrows in Fig. 15, a magnetic field is applied to each film M which will become the GMR element in the longitudinal direction of the narrow zonal portion of each film M in the state wherein the quartz glass 10a1 is placed on the upper surface of the plate 93.

[0045]

The present embodiment utilizes this magnetic field for magnetizing the bias magnet films 11b to 14b, 21b to 24b, 51b to 54b and 61b to 64b as well as for matching the direction of magnetization in each magnetic domain in the free layer F with the direction in the initial state. That is , magnetization in each magnetic domain in the free layer F is initialized.

[0046]

Subsequently, the relative relationship between the quartz glass 10a1 having the film M which will become the GMR element formed thereon and the magnet array MA (plate 93) is changed as shown in a plan view of Fig. 16, whereby the surface on which the film M which will become the GMR element is formed is arranged to be brought into contact with the upper surface of the plate 93. At this time, the quartz glass 10a1 and the

magnet array MA are relatively arranged such that each cross-point of the cutting plane line CL of the quartz glass 10a1 that becomes each side of the magnetic sensors 10 and 50 is matched with the respective center of gravity of four adjacent permanent bar magnets 92 ..... 92. Accordingly, as shown by arrows in Fig. 16, a magnetic field is applied to each film M which will become the GMR element in the direction perpendicular to the longitudinal direction of the narrow zonal portion of each film M in the state wherein the quartz glass 10a1 is placed on the upper surface of the plate 93.

【0047】

The present embodiment utilizes this magnetic field for performing a heat treatment to fix the direction of magnetization in the fixed layer P (pinned layer of the fixed layer P). Specifically, the plate 93 and the quartz glass 10a1 are fixed to each other by the cramp C with the state shown in Fig. 16, then, the resultant is heated in a vacuum to 250 to 280 C and left for about four hours in this state.

【0048】

Thereafter, the quartz glass 10a1 is removed to form a wiring or the like for connecting each film M, and finally, the quartz glass 10a1 is cut along the broken line shown in Fig. 10. As described above, a great number of magnetic sensors 10 and 50 shown in Fig. 1 are simultaneously produced.

【0049】

As described above, a magnetic sensor according to the embodiment of the present invention has bias magnet films 11b ..... 11b provided at both ends of the free layer F in the longitudinal direction for producing in the free layer a bias magnetic field in a predetermined direction

(in the longitudinal direction of the free layer), whereby the direction of magnetization in each magnetic domain in the free layer can stably be maintained in the predetermined direction when an external magnetic field is not present.

[0050]

Further, the initializing coils 31 to 34 and 41 to 44 are energized under a predetermined condition to thereby generate an initializing magnetic field for returning the direction of magnetization in each magnetic domain in the free layer to the direction (i.e., the longitudinal direction of the free layer) same as the direction of the bias magnetic field by the bias magnet films, whereby the direction of magnetization in each magnetic domain in the free layer can assuredly be returned to the initial state even if the direction of magnetization is disturbed by applying a strong magnetic field to the free layer. As a result, a hysteresis that occurs when the external magnetic field is in the vicinity of "0" with respect to the change of the external magnetic field can be maintained small by the magnetic sensors 10 and 50. Thus, the magnetic sensor is capable of detecting a minute magnetic field with high precision over a long period.

[0051]

Further, according to the production process of the magnetic sensor according to the embodiment of the present invention, there is prepared a magnet array MA that is configured such that plural permanent magnets are arranged at a lattice point of a tetragonal lattice and the polarity of the magnetic pole of each permanent magnet is different from the polarity of the other adjacent magnetic pole spaced by the shortest route. Therefore, the direction of magnetization in each magnetic domain in the free layer is

initialized and the bias magnet films are magnetized, and further, a pinning is performed by pinning the direction of magnetization in the magnetic layer that becomes a pinned layer. Accordingly, plural GMR elements having different magnetic field detecting directions (perpendicular to each other) can easily and efficiently be formed on a single chip, thereby being capable of manufacturing with low cost a magnetic sensor of a single chip which is capable of detecting at least respective magnetic fields whose magnitude is changed in the directions perpendicular to each other.

[0052]

The present invention is not limited to the above-mentioned embodiment, but various modifications can be applied within the scope of the present invention. For example, as shown in Fig. 20 representing a first X-axis GMR element 201 taking as a representative example, narrow zonal portions 201a may be separated at the upper portion of the bias magnet films 11b ..... 11b disposed below both ends thereof. Further, an initializing coil 202 may be a double spiral type coil wherein a spiral coil 202-1 having a center point P1 and a spiral coil 202-2 having a center point P2 are connected to each other. In this case, the first X-axis GMR element 201 is arranged between the center point P1 and the center point P2, resulting in that currents parallel to each other flow in the same direction through each conductor section of the initializing coil 202 passing below the first X-axis GMR element 201, thereby generating the initializing magnetic field. Moreover, the initializing coil may be a multi-layered coil or may be a toroidal coil. Further, a testing coil that generates a testing magnetic field, in the direction perpendicular to the initializing magnetic field generated by the initializing coil, for checking a function of each GMR element may also

be disposed in the insulating layer above or below (Z-axis direction) the initializing coil.

【Brief description of the drawings】

【Fig. 1】 Fig. 1 is a plan view of a magnetic sensor in accordance with an embodiment of the present invention;

【Fig. 2】 Fig. 2 is a schematic enlarged plan view of a first X-axis GMR element shown in Fig. 1;

【Fig. 3】Fig. 3 is a schematic sectional view of the first X-axis GMR element shown in Fig. 2 cut by a plane along a line 1 - 1 in Fig. 2;

【Fig. 4】 Fig. 4 is a view showing a structure of a spin valve film of the first X-axis GMR element shown in Fig. 2;

【Fig. 5】 Fig. 5 is a graph showing by a solid line a resistance change of the first X-axis GMR element shown in Fig. 1 for a magnetic field changed in the X-axis direction and showing by a broken line a resistance change thereof for a magnetic field changed in the Y-axis direction;

【Fig. 6】 Fig. 6(A) is an equivalent circuit diagram of an X-axis magnetic sensor included in the magnetic sensor shown in Fig. 1; Fig. 6(B) is a graph showing a change of output for the magnetic field changed in the X-axis direction of the X-axis magnetic sensor;

【Fig. 7】 Fig. 7(A) is an equivalent circuit diagram of a Y-axis magnetic sensor included in the magnetic sensor shown in Fig. 1; Fig. 7(B) is a graph showing a change of output for the magnetic field changed in the Y-axis direction of the Y-axis magnetic sensor;

【Fig. 8】 Fig. 8(A) is another equivalent circuit diagram of an X-axis magnetic sensor included in the magnetic sensor shown in Fig. 1; Fig. 8(B) is a graph showing a change of output for the magnetic field changed in

the X-axis direction of the X-axis magnetic sensor;

【Fig. 9】 Fig. 9(A) is another equivalent circuit diagram of a Y-axis magnetic sensor included in the magnetic sensor shown in Fig. 1; Fig. 9(B) is a graph showing a change of output for the magnetic field changed in the Y-axis direction of the Y-axis magnetic sensor;

【Fig. 10】 Fig. 10 is a plan view of a quartz glass, during a process for fabricating the magnetic sensor shown in Fig. 1, having the spin valve film formed thereon;

【Fig. 11】 Fig. 11 is a plan view showing a metal plate for preparing a magnet array used upon fabricating the magnetic sensor shown in Fig. 1 and a permanent bar magnet inserted into the metal plate;

【Fig. 12】 Fig. 12 is a sectional view of the magnet array used upon fabricating the magnetic sensor shown in Fig. 1;

【Fig. 13】 Fig. 13 is a perspective view wherein a part of a magnet of the magnet array shown in Fig. 12 is taken out;

【Fig. 14】 Fig. 14 is a view showing one of processes for fabricating the magnetic sensor shown in Fig. 1;

【Fig. 15】 Fig. 15 is a conceptional view showing a method of magnetizing a bias magnet film of each GMR element of the magnetic sensor shown in Fig. 1;

【Fig. 16】 Fig. 16 is a conceptional view showing a method of pinning a direction of magnetization in the pinned layer of each GMR element of the magnetic sensor shown in Fig. 1;

【Fig. 17】 Figs. 17(A), 17(B), 17(C) and 17(D) are plan views each showing a state of magnetization of the free layer and the bias magnet films of the GMR element, wherein Fig. 17(A) is a view showing a state of the bias

magnet films before they are magnetized, Fig. 17(B) is a view showing a state of the bias magnet films after they are magnetized, Fig. 17(C) is a view showing a state in which an external magnetic field is applied and Fig. 17(D) is a view showing a state after the external magnetic field is eliminated;

【Fig. 18】 Fig. 18(A) is a graph showing a resistance change, for the external magnetic field, of the GMR element in a state before the bias magnet films are magnetized; Fig. 18(B) is a graph showing a resistance change, for the external magnetic field, of the GMR element in a state after the bias magnet films are magnetized;

【Fig. 19】 Figs. 19(A), 19(B) and 19(C) are plan views each showing a state of magnetization of the free layer and the bias magnet films of the GMR element, wherein Fig. 19(A) is a view showing a state of the bias magnet films before they are magnetized and that the external magnetic field is not applied, Fig 19(B) is a view showing a state in which a strong external magnetic field is applied and Fig. 19(C) is a view showing a state after the strong external magnetic field is eliminated; and

【Fig. 20】 Fig. 20 is a schematic enlarged plan view of a first X-axis GMR element of a magnetic sensor according to another embodiment of the present invention.

【Explanation of numerals】

10,50···magnetic sensor; 11-14, 21-24, 51-54, 61-64···GMR element; 11a-14a, 21a-24a, 51a-54a, 61a-64a···narrow zonal portion; 11b-14b, 21b-24b, 51b-54b, 61b-64b···bias magnet film; 31-34, 41-44, 71-74, 81-84 ···initializing coil; MA···magnet array

【Abstract】

【problem to be solved】 The present invention aims to provide a magnetic sensor provided with a magnetoresistive effect element capable of stably maintaining a direction of magnetization in a magnetic domain of a free layer.

【means to solve the problem】

The magnetic sensor includes a mangetoresistive effect element provided with narrow zonal portions 11a ..... 11a including a pinned layer and a free layer. Disposed below both ends of the free layer are bias magnet films 11b ..... 11b composed of a permanent magnet that applies to the free layer a bias magnetic field in a predetermined direction and an initializing coil 31 that is disposed in the vicinity of the free layer and applies to the free layer a magnetic field having the direction same as that of the bias magnetic field by being energized under a predetermined condition. Further, magnetizing the bias magnet films and fixing the direction of magnetization of the pinned layer are performed by a magnetic field formed by a magnet array configured such that plural permanent magnets are arranged on a lattice point of a tetragonal lattice and a polarity of a magnet pole of each permanent magnet is different from a polarity of the other adjacent magnet pole spaced by the shortest route.

【drawing chosen】 Fig. 2